Advanced Battery Technology Program

Judith A. Jeevarajan, Johnson Space Center Eric C. Darcy, Johnson Space Center

Advanced battery test programs strengthen the existing database that also serves as a source of information for new projects requiring batteries both in the government-furnished equipment as well as payload projects. The tests are geared to obtain as much information as is possible within a reasonable cost and timeline. The programs carried out in the Fiscal Year 2006 – Fiscal Year 2007 time frame included cells of the lithium-ion chemistry of both the polymer as well as cylindrical cell designs. Three of those will be discussed here. Other cells tested include SKC 5.0 Ah and 2.5 Ah, SKC 4.5 Ah high-rate cells, and Saehan high-rate cells.

A new Li-ion 4.0 Ah pouch cell from GS Yuasa was tested to determine its performance and safety. The cell is of a laminate pouch design with liquid electrolyte. The rate, thermal, and vacuum performance capabilities were tested to determine the optimum parameters. Under vacuum conditions, the cells were cycled under restrained and unrestrained configurations. The burst pressure of the laminate pouch was also determined. The overcharge, overdischarge into reversal, and external short circuit safety tests were performed to determine the cell's tolerance to abuse. Table 1 provides a summary of the data obtained from the rate capability tests. The tests at different temperatures indicated that the cells provided an approximately 3% drop in performance at 0°C compared to that obtained at 25°C. The cells also showed a drop in

| Protocol | Init. Cap (Ah) | Final Cap (Ah) |
|-----------|----------------|----------------|
| 0.5C/0.5C | 3.57 | 3.43 (#175) |
| 0.5C/1C | 3.52 | 3.49 (#43) |
| 0.5C/2.5C | 3.52 | 3.49 (#49) |
| 1C/0.5C | 3.56 | 3.42 (#192) |
| 1C/1C | 3.55 | 3.42 (#200) |
| 1C/2.5C | 3.53 | 3.35 (#200) |
| 0.5C/5C | 3.22 | 2.93 (#158) |
| 0.5C/7.5C | 2.77 | 1.61 (#108) |
| 0.5C/10C | 1.86 | 1.0 (#106) |

Table 1. Discharge capacity trend using the various charge/ discharge protocols.

performance with cycles at higher temperatures of 40 and 55°C. For the 55°C run, a slight drop in performance was observed between the first and last cycle tested. The overcharge tests showed that the cells were tolerant to an overcharge over the time period tested with temperatures reaching up to 70°C at the end of that test period. The overdischarge test was performed on the cells to remove an additional 150% of the original capacity. The maximum temperature recorded during this test was 30°C. The cells did not accept charge after this test but did not vent, burst, or leak electrolyte. During the short circuit test, the maximum current spike recorded within the first few milliseconds was about 50 A. The maximum temperature obtained during this test was 27°C. No venting or leakage of the cells was observed, but the cells were nonfunctional after the test.

In summary, the GS Yuasa laminate pouch cells with liquid electrolyte provided remarkable performance under the conditions tested, especially those at higher discharge current rates. The cells showed excellent performance even at low temperatures with only a 3% drop in capacity at 0°C compared to that obtained at 25°C. The tests under vacuum conditions indicated that the cells should be restrained in a vacuum environment for consistent performance. Although the cells were not usable after all the abuse conditions tested, they did not display any hazardous results of electrolyte leakage, venting, or fire.

The Intec Li-ion cells were the state-of-the-art cylindrical 18650 type of 2-Ah capacity. The test program included rate capability, performance at different temperatures, vent and burst pressure, overcharge, overdischarge, external and simulated internal short (crush), and heat-to-vent. The cells lost about 16% capacity under a 1C charge and discharge rate and approximately 3% at a C/5 rate of charge and discharge after 200 cycles. The cells performed well at low temperatures and provided almost 50% of the original capacity on the first cycle at -30°C and greater than 75% on the second cycle (figure 1). The vent pressure for the cells was 200 psig and the burst pressure was about 850 psig, providing more than the 2.5 ratio required. The cells were tolerant to an overcharge with a current of 1 A to 12 V for 6 hours, and the maximum temperature reached was only 44°C.

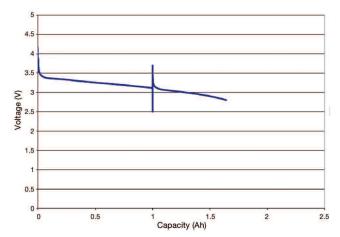


Fig. 1. Performance at -30°C of the Intec 2.0 Ah Li-ion cells.

The cells showed tolerance under the overdischarge into reversal test but were not functional after the removal of 150% of the original capacity. The cells char completely and exhibit sparking and flaming at temperatures above 150°C. The simulated internal short test did not result in any significant event. The external short test with a load of 50 mohms displayed a current spike of 40 A and a maximum temperature of 70°C. In summary, the cells performed best at C/5 rates and worst at C rates of charge and discharge. The cells exhibited tolerance to abuse except at high temperatures, where they vent with significant sparks and fire.

The A123 cells were studied for their high-rate capability and inherent safety. The cells are made with a lithium iron phosphate cathode with inherent safety due to the low voltage on the cells as well as the difficulty associated with the release of oxygen from the cathode at high voltages. The A123 cells are currently powering the DeWalt power tools, and an interest has been displayed by the crew office to use this tool for future extravehicular activity missions. In an attempt to understand this new lithium iron phosphate chemistry and its safety, cells were procured from Valence in the past (reported in Biennial Report in 2005), but they were of a medium-rate capability. The cells from A123 have quick recharge as well as discharge capability. About 25 cells were provided to Johnson Space Center by the vendor, and a small test program that included some critical performance and safety tests was conducted. The cells were tested at different charge and discharge rates and were found to provide excellent performance at high rates of charge and discharge. Under continuous cycling with discharge currents of 60 A, 49% of the nameplate capacity

was obtained; and at 46 A, about 56% of the capacity was obtained. The cells were discharged with a continuous load of 23 A at different temperatures; below –20°C, no performance is obtained.

The cells were discharged under a wide temperature range of -30 to 50°C with a constant current of 2.3 A and 10-second pulses of 23 A at every 10% state-of-charge. At -30°C, the pulses had to be reduced to 100-msec width to obtain pulse performance. The maximum pulse capability of the cells was determined by subjecting the cells to the advertised 130-A pulses. Although the voltage at first falls below 1.5 V, due to internal heating, the cells perform better under the rest of the pulses (figure 2).

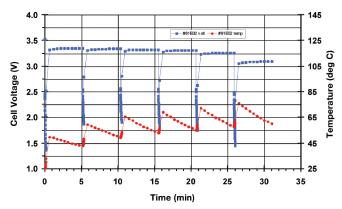


Fig. 2. Maximum pulse (130 A) capability of A123 lithium iron phosphate cells.

Under conditions of abuse, the cells displayed tolerance at the cell level to overcharge at 1C and 10C rates. But when six cells were connected in series and overcharged with a 1C current, the cells exhibit violent venting, smoke, and fire.

Mobile Power Solutions and Symmetry Resources Inc. carried out a majority of the tests. Eric Darcy and Gilberto Varela offered support in these test programs. Geminesse Dorsey, Mike Salinas and Tony Chu, Tony Parish, Randall Parish, and Jim Fowler of the Energy Systems Test Area also contributed.